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Multicast Routing Protocols for Wireless Sensor Networks:A comparative study

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Abstract-Wireless sensor network comprises of a set of sensor nodes that communicate among each other using wireless links and work in an open and distributed manner because of less number of resources on the nodes. The sensor nodes sense information about an event from the ambiance and then the information is forwarded to a sink node for further processing and analyzing. The sensed information can be forwarded in many ways, earlier uni cast routing was there to a single sink node,but due to the wide variety of WSN applications the presence of multiple sinks is realized which necessitates multicast routing for efficient data dissemination to multiple destinations. For any disaster surveillance or fire handling emergency scenarios various multicast routing protocols have been proposed by many researchers. This paper focuses on providing a survey of the existing multicast routing protocols by presenting approach, their advantages and disadvantages. Further a comparative study of various multicast protocols is done on the basis of different parameters to identify different issues and challenges that need to be resolved for each one of them.

Keywords-*Wireless sensor networks (WSNs); Geographic and energy aware routing (GEAR); Very Light weight mobile multicast system (VLMP) Light weight protocol for multicast (TNT/PTNT); Branch aggregation multicast protocols (BAM); Optimized distributed multicast routing protocol (ODMRP); HGMR(hierarchical Geographic Multicast routing); GMR(Geographic Multicast routing); HRPM (Hierarchical Rendezvous point multicast); Energy-balancing multicast routing protocol (EMRP); Packet Delivery Ratio (PDR).*

I. INTRODUCTION

Due to the advances in the Micro-electro-Mechanical systems (MEMS) and low power integrated circuits, digital electronics gave rise to the development of micro sensors (Sohrabi,2000) [1]. In the past few years there was a great research done by researchers in the field of sensor networks to emphasize the potential of cooperation among sensors in collecting the data, processing, coordinating, management of the sensing activity and data flow to sink. For the twenty-first century WSN is considered as one of the most important technologies [1]. A WSN contains hundreds or thousands of sensor nodes which are densely deployed in an unattended manner with the capabilities of sensing, wireless communication and able to compute in large scale wireless sensor networks. For WSNs there are certain unique characteristics which include denser level of node deployment, higher unreliability of sensor nodes and severe energy, computation and storage constraints .Thus the unique characteristics and constraints put a limelight on the new challenges for the development and application of WSNs.

A. Communication architecture of WSN

The schematic diagram below represents the communication architecture and sensor node components of wireless network [2].

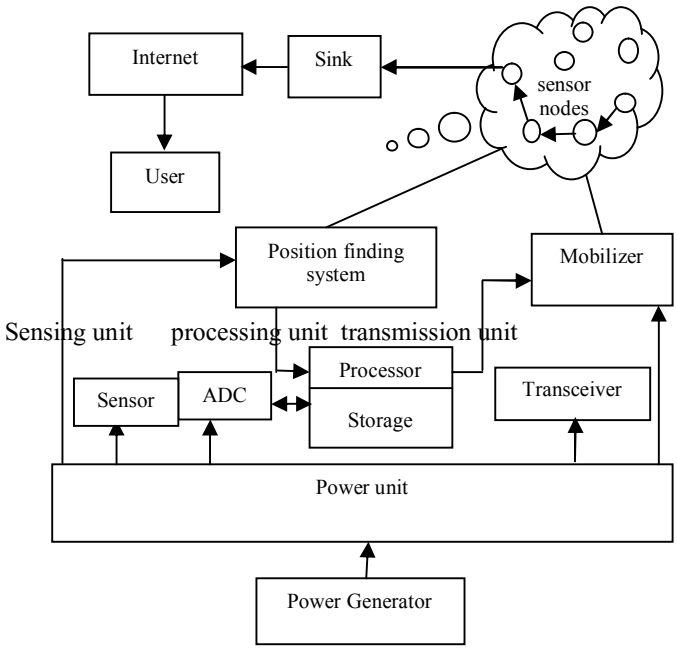

Figure1. *Components of a Sensor Node*

The sensor nodes comprise sensing, transmission, Mobilizer, processing, position finding system and power units. This diagram represents that the sensor nodes are usually scattered in a sensor field, an area where these sensor nodes are deployed. To produce higher quality information about the physical environment these sensor nodes coordinate among themselves. The decision of each sensor node is based on its mission, the current information, knowledge of computing, communication and energy resources. These sensor nodes are capable of communicating with each other or directly to the external base station. A base station can be either a fixed node or a mobile node which is capable of connecting the sensor network to an existing communications infrastructure or to the internet where a user can have access to the reported data. The four basic components of sensor networks are explained in Figure 1 are distributed and localized sensors, an interconnecting network, A central point of information clustering, A set of computing resources at that central point to manage the data correlation, status queuing as well as data mining.

B. Characteristics of WSN

WSN includes number of low power, low cost and multifunctional sensor nodes which are deployed in a region of interest.The sensor nodes are small in size but they are equipped with sensors, embedded microprocessors and radio transceivers [3]. They are having sensing, data processing and communication capabilities. As compared to traditional wireless communication networks for example MANET and cellular systems, sensor nodes possess some unique characteristics like densely deployed sensor nodes, battery powered sensor nodes, self configurable, they should be application specific, unreliable sensor nodes, the node failure and environmental obstructions led to a high degree of dynamics so, frequent network topology changes and network partition are introduced in WSN.

C. WSN applications

WSN possess a wide variety of applications in different fields like [3]

1.) Environmental applications: include forest fire detection, microclimates, flood detection and precision agriculture.

2.) Health applications: are monitoring doctors and patients within a hospital, drug administration, elderly assistance, remote monitoring of psychological data and many more.
3.) Military applications: include monitoring of friendly forces and equipments, monitoring of enemy forces, military-theatre and battlefield surveillance, targeting, battle damage assessment, nuclear and chemical attack detection.
4.) Home applications: inculcate instrument environment and home automation.
5.) Commercial applications: include inventory control, vehicle tracking and detection, environmental control in industrial and office buildings and traffic flow surveillance.

D. Challenge in WSN

some hurdles and challenges are there which includes limited functional capabilities, including problem of size, power factors related to environmental factors, transmission channel factors, topology management complexity, node distribution, scalability issues and standard versus proprietary solutions [4].

II. ROUTING PROTOCOLS IN WSN

Routing in wireless sensor networks differ from traditional wireless communication network (MANET) as the number of sensor nodes in wireless sensor networks can be several orders of magnitude which is higher than that in MANET, sensor node do not have any unique ID, sensor nodes are cheaper than nodes in MANET,power resources of sensor nodes should be very limited, sensor nodes are more limited in their computation and communication capabilities than MANETs, moreover sensor nodes are prone to failures. Therefore there is no infrastructure, sensor nodes may fail, wireless links are unreliable, and routing protocols have to meet strict energy saving requirements [5].

Data Centric Protocols
Hierarchical Protocols
Location Based Protocols
Energy efficient Protocols

Table 1. *Routing protocols for WSN*

So, it is imperative to study routing protocols for wireless sensor networks. The routing protocols proposed for WSN are classified into four main categories as,

- Data centric protocols. These are those protocols which are query based and to reduce the repeated transmission, these protocols depend on the naming of data of interest.
- Hierarchical protocols. These are those protocols in which the sensors in the network are divided into different clusters . It is an efficient way to reduce energy consumption within a cluster by introducing data aggregation and fusion to decrease the number of transmitted messages to the base station.
- Location based protocols. These protocols utilize the position information of nodes to relay data to the destinations. On the basis of the incoming signal strength the distance between the neighboring nodes is estimated. Here the region which is to be sensed is known in advance using the location of sensors and therefore the query generated will be diffused only to that particular region which will significantly estimate the number of transmissions.
- Energy efficient protocols. These protocols are to balance the energy consumption in the network as they are energy efficient as they utilize the power in an effective manner and consume less energy.

E. Classification on the basis of transmission

The routing protocols are classified on the basis of how the messages are transmitted from source to destinations. Basically the classification is described as follows:

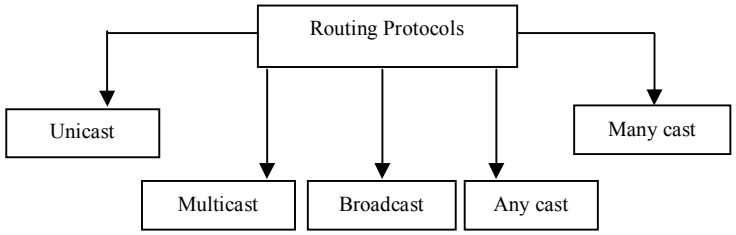

Figure 2. *Classification on the basis of messages transmitted [6]*

Protocols can be classified into broadcast, Multicast, unicast, anycast, many cast routing protocols. Unicast routing protocols are to send a message, which is generated by a single node to a single destination [6]. Multicast routing protocols are to deliver messages from a single source to a set of destinations which result in minimization of consumption of network resources.Broadcast is to send a message from a sensor node to every other node in the network. Data delivery to any node in a particular network is known as anycast and many cast is the combination of anycast and multicast.

F. Routing challenges and design issues in WSN

Network layer is responsible for routing in WSN. It is designed on the basis of power efficiency, data aggregation and attributed based addressing and location awareness [7]. There are various applications of WSN, but there are some limitations such a limited bandwidth, limited computation power and limited energy of the wireless links connecting sensor nodes. The routing challenges and design issues in WSN are low node cost, self configurability, small node size, scalability, fault tolerance, reliability, adaptability, security, QoS support, data reporting method, channel utilization [8].

III. MULTICAST ROUTING PROTOCOLS

Use of multicast is of great interest, it is used to send the same report to several sinks. Multicasting is introduced to reduce bandwidth consumption in the network for various applications which include data replication, assignment of tasks and sending of commands to a specific group of sensors, queries to multiple sensors etc. Fire monitoring network is an example of multicast routing as in this network sensors are deployed in a building to detect the probability of fire. If a building catches fire at some point then the sensors will sense the smoke or abrupt rise in temperature at that location. Further the sensed information is sent to a number of nearby sensors at other parts of the building to adjust their sampling rate and information the offire responders such as fire brigade office, ambulance service, hospitals etc. Hence multicasting is done to allow the fire rescue team to start their operations in time with more efficiency. Earlier, the unicast routing protocols were there which were effective to provide unicast routing in resource-constrained scenarios, adapt very fast to challenging network conditions, overhead in a network should be low due to limited battery, storage capacity, bandwidth and processing power of sensor nodes, so there was a need to have such effective routing to alleviate the overall consumption of resources in the network as here in multicast routing the few copies are sent to the all destinations as possible of each datagram. The use of minimal amount of control information is there.

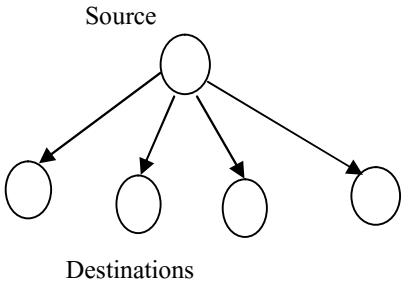

Figure 3. *Multicasting Concept*

A. Approach for Multicast Routing

There are different configuration techniques proposed to support multicast routing but here in this paper, the four approaches for multicast routing are discussed as shown in below Figure 4 [9].

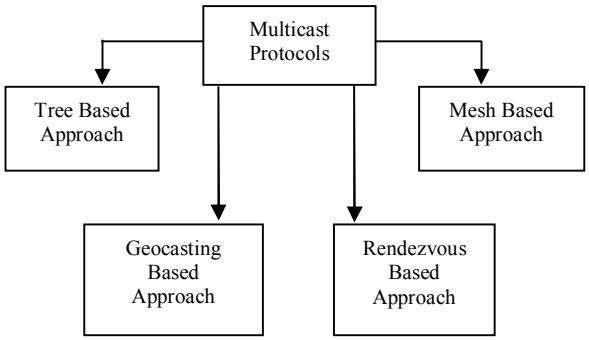

Figure 4. *Different approaches of multicast routing*

The proposed multicast routing protocols are based on one of these approaches and inherit their features. In the following section, an insight is provided to these techniques prior to proceed for discussion on Multicast routing protocols.

- Tree Based Approach. This approach provides shortest and loop free paths and it is easy to leave or join a multicast group. Multicast tree is constructed on the basis of different parameters such as hop count and link quality indicator like delay, bandwidth or aggregated weight of the parameters. One of the drawbacks of this approach is that if any link failure occurs then this may cause the isolation of complete branch from the tree which may further contain multiple nodes.
- Mesh Based Approach. Here all the group members form mesh connectivity in order to achieve a connection of every member with other members. Here route discovery and mesh construction is accomplished through broadcasting central points. This is more reliable and robust approach especially when the nodes mobility increases; moreover it estimates the traffic problems. Here if there is any link failure then the overall communication is not affected.
- Geocasting Based Approach. Geocast communication is limited to the destination nodes as the data packets are delivered to a set of nodes lying within a specific geographical area. The geocast group management is defined with the help of its geographic location. In heterogeneous networks this approach works efficiently but still there are some scalability concerns which are not suitable for large networks.
- Rendezvous Based Approach. Here a subset of a node or a single node acts as rendezvous point (RP) in the network. The RP's are there to collect the sensed data from different sensor nodes and further transfer them to the sink nodes. A disadvantage of this approach is that it is a time consuming process and a big damage to the network occurs if RP failed.

B. Multicast routing categories

Multicasting is a technique used to reduce the energy consumption in the network with the property of sending few copies as possible of each datagram to reach all destinations. This section of the paper focuses on three multicast routing protocols [10]. Categories as illustrated below:

1.) Tree Based Multicast Protocols: These protocols deliver multicast packet which relying on forwarding states that need to be maintained at nodes within a path. The drawbacks are control information flooding and storage for providing table establishment and maintenance which results in overhead in WSN.
2.) Location Based Multicast Protocols: The multicast packets carry the location information of the destination nodes. It is beneficial in reducing the computation at every forwarding node in a path while searching for next forwarding node which results in excessive processing of CPU and energy consumption.
3.) Source Based Protocols: These protocols make a path tree at a source and a multicast packet is encoded with the path tree, information is propagated which requires no states in WSN nodes.

There are many source based, tree based and location based algorithms for routing with some advantages and disadvantages.

C. Challenges

As in WSN energy, memory and CPU power is limited; similarly in wired networks routers are responsible for handling packet replication and forwarding. The management for multiple groups and multicast trees requires memory and processing power, so for WSN it is not feasible to have overlay connection establishment all the time which results in higher energy consumption and hence network lifetime is reduced [11].

IV. VARIOUS MULTICAST ROUTING PROTOCOLS

The multicast routing protocols plays a very important role in emergency handling applications, as these protocols are to minimize energy and bandwidth consumption, when there are multiple dispersed destination nodes. This section focuses on some multicast routing protocols as shown in Figure 5. The rest of the paper is organized as follows. Section A provides an overview and classification of multicast routing protocols in WSN. In section B different features of existing multicast routing protocols are discussed. Section C focuses on similarities and dissimilarities offered by these protocols [11]. Further, in section D comparison of different protocols is done on the basis of different parameters. Finally section V concludes this paper.

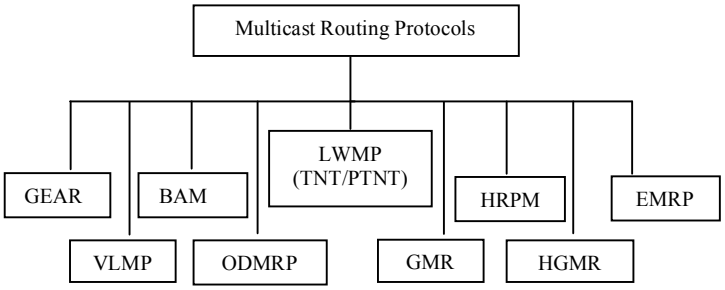

Figure 5. *Different multicast routing protocols*

A. Overview of Multicast Routing Protocols

The multicast routing protocols are classified on the basis of approach and category further an overview of protocol is provided including need, advantages and disadvantages [12]. Table 2. shows the existing multicast routing protocols according to the year in which they proposed based on the historic design.

Year	Location based	Energy based	Rendezvous based
2001	GEAR	-	-
2003	VLMP	-	-
2005	LWMP	-	-
2005	-	BAM	-
2006	ODMRP	-	-
2006	GMR	-	-
2007	-	-	HRPM
2007	HGMR	-	-
2008	EMRP	-	-

Table 2. *Existing multicast routing protocols based on the historical design[12][13]*

1. Geographic and Energy Aware Routing (GEAR):

Geographic and energy aware routing in wireless sensor networks shown by Yu et al.This is a location based protocol. The main goal of the proposed protocol is to use energy aware and geographically informed neighbor selection heuristics to route a packet towards the targeted region and within a region it uses a recursive geographic technique to disseminate the packets[13]. This protocol outperforms in terms of reducing energy consumption for route setup and also performs better than GPSR (Greedy perimeter stateless routing in terms of packet delivery. The contribution of GEAR protocol is experimental analysis and to investigate the optimization problems and tradeoff between distance and energy balancing [14].

Advantages:

- It exhibits longer network lifetime than non energy aware geographic routing algorithms.
- It reduces or minimizes delay due to distance travelled on geographic routing and ameliorates energy balancing.

Disadvantages:

- Incapable of defending bogus routing information, Sybil attack and selective forwarding, so security issue are of concern.
- Power management and scalability is limited.

2. Very Light Weight Mobile Multicast System (VLMP):

It is an advanced version of (Light Weight Protocol for Multicast) LWMP using PTNT approach for multicast communication. This protocol was proposed by Anmol Seth et al. Here every node is identified by a unique ID. The ID consists of multiple portions, personal identification of sensor node, identification of the multicast group to which it belongs etc. A request is sent for subscription to any member of the multicast group to become a member of the multicast group and then the acknowledgment is received. This protocol uses the flooding mechanism for transfer beacons to underlying sensor nodes [14]. Here unicast routing is used in a multicast group for communication between sensor and sink node, whereas communication between sink and sensor nodes are handled with the help of multicast routing.

Advantages:

- This is a stateless protocol.
- This protocol supports mobility as well as fault tolerance.

Disadvantages:

- As compared to other protocols this protocol has high delay, overhead and scalability problem.
- This is an energy inefficient protocol.

- Do not support real time communication.

3. Light Weight Protocol for Multicast (TNT/PTNT):

Qing Ye et al. proposed a new protocol which works efficiently with limited resources in WSNs. Here track and transmit (TNT) approach is used to check the position of sink node in the network, and a sink node is mobile. The new position of sink node is tracked every time and the data is forwarded towards it. The improved form of TNT was also proposed which is known as priced track and transmits (PTNT) which is a more efficient approach [15]. This protocol provides better results than VLMP protocol in terms of overhead and delay.

Advantages:

- PTNT provides maximum number of packets at destination.
- Easy to implement in both static and mobile scenarios of WSNs.
- Provides guarantee that after each routing step the data will be more nearer to the destination as compared to previous location.

Disadvantages:

- It has high overhead because of the extra traffic generated for tracking and transmission.
- There is energy inefficient protocol due to high consumption of energy.
- Scalability issues as any change in the network size and node density will result in decrease in efficiency and reliability.

4. Branch Aggregation Multicast Protocol (BAM):

A.Qura et al. proposed a multicast protocol for multicast communication in wireless sensor networks which is known as Branch Aggregation Multicast protocol (BAM). This protocol is based on two approaches as,

a) Single hop aggregation (S-BAM) which is responsible to aggregates radio transmission within a single hop and to enable single transmission to multiple receivers.

b) Multiple path aggregation (M-BAM) which aggregates multiple paths into few and control the range of transmission which results in decreasing the number of branches. This technique of merging both the approaches, S-BAM and M-BAM is helpful to reduce overhead as well as energy consumption. This protocol can perform better in terms of heterogeneous networks where multiple protocols are involved during the communication process [16].

Advantages:

- It focuses on decreasing the bandwidth utilization and energy consumption in the energy constraint wireless sensor network.
- It is an energy inefficient protocol.

Disadvantages:

- Scalability issues are there.
- This protocol do not support real time communication so not suitable for WSN as increase in number of attacks may cause a lot of disruption.
- Event driven protocol so cannot perform efficiently when we need data without any event occurrence in the network.

5. Optimized Distributed Multicast Routing Protocol (ODMRP):

This protocol was introduced by Yang Min et al.This is the improved version of the earlier Distributed Multicast Routing Protocol (DMRP). In ODMRP the construction of multicast tree is based on shortest path from source to sink node. This is a two phase process in which the message is invited first and then sent further, the acknowledgment is also provided. The need for this protocol is that as the old protocols were not considering

multisinks in the network so such a protocol was designed which uses tree based approach for multicast communication [16].

Advantages:

- This protocol provides scalability.
- In this protocol multisinks are considered in the network.

Disadvantages:

- Because of two phase communication the high encoding overhead is introduced.
- High delay problem is there in ODMRP because of route establishment between source and multiple sinks.

6. Geographic Multicast Routing Protocol (GMR):

Geographic multicast routing protocol was proposed by Juan A.Sanchez et al. It is fully distributed and operates in a localized manner in tree formation. This is a Geocasting based protocol. Here each packet carries the ID's of multicast destinations and then forward it to each of the destination independently in a greedy manner. Those destinations which share the same next hop will go along the same way in the hop-by-hop forwarding in GMR.

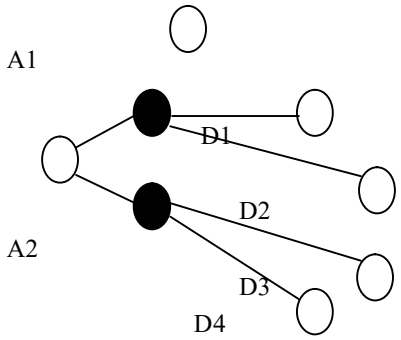

Figure 6. *Forwarding node selection in GMR*

As earlier centralized membership management is done at the multicast root, but in GMR it is done along the multicast tree to send a data packet down the multiple branch of the multicast tree using one broadcast transmission [17].

Advantages:

- Bandwidth utilization is provided to minimize the total number of transmissions for accomplishing a multicast task.
- GMR protocol is an energy inefficient protocol and it exhibits high delay during communication.

Disadvantages:

- Scalability issues are there for large scale networks.
- Too much encoding overhead [18].
- Energy consumption is limited to the nodes on the routing paths as for every data delivery same paths are created.
- In GMR there are more destinations so more complex is the evaluation,as the cost and the progress need to evaluate for every subset of destinations at every hop[19].

7. Hierarchical Rendezvous Point Multicast (HRPM):

Hierarchical Rendezvous Point Multicast was introduced by Saumitra M.Das et al. It reduces encoding overhead of location based multicast protocols by constructing a hierarchy by dividing the network into multicast groups and then into subgroups, then further each subgroup is restrained by its coordinator which is known as access point (AP) [20].

This protocol uses the concept of mobile geographic hashing to reduce the maintenance of AP (access point) and RP (rendezvous point) nodes at virtually no maintenance cost. The need for this protocol is to construct and maintain hierarchy to have low encoding overhead. HRPM is designed to work for multicast communication and for HRPM there is no need to take care of cost factors like in GMR protocol [21].

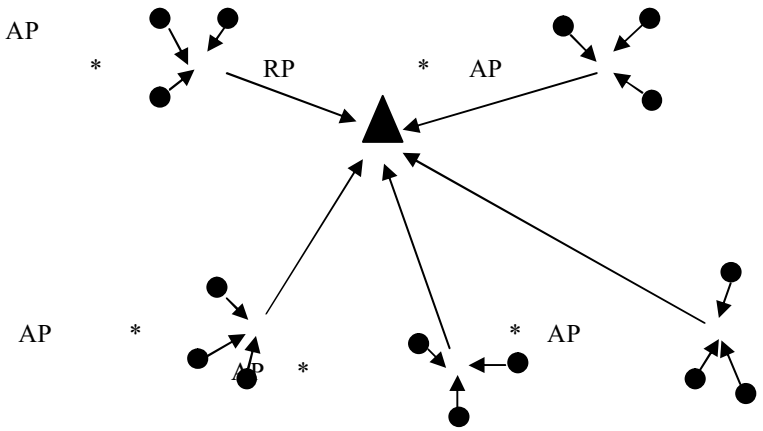

Figure 7. ***Group management in HRPM***

Advantages:

- Reduced encoding overhead and delay is less.
- Scalable protocol and its performance do not decrease due to any change in network size or node density.

Disadvantages:

- Consumes a lot of energy and therefore inefficient in terms of packet transmission as at each node along the source→APs (access point) or the AP→Member tree.
- Packet unicast to more than one neighbor node which consumes bandwidth.

7. Hierarchical Geographic Multicast Routing Protocol (HGMR):

Hierarchical Geographic Multicast Routing Protocol was proposed by Dimitrios Koutson ety al.[20]. HGMR put together the GMR and HRPM protocol. It includes hierarchical decomposition of a multicast group into subgroups of manageable size which results in reduced encoding overhead using HRPM concept of mobile geographic hashing and within each subgroup it uses GMR concept. Here the source builds an overlay tree, the source→to→AP tree and another overlay tree as AP→to →member tree. To transmit data packets from source the unicast based forwarding strategy of HRPM is used to propagate data packets to each AP along the source→to→AP overlay tree and in case of constructing an AP→to →member overlay tree in each cell. Here local multicast scheme is used to forward a data packet along multiple branches of the multicast tree in one transmission. Hence it combines the high forward efficiency of GMR with low encoding overhead of HRPM [21].

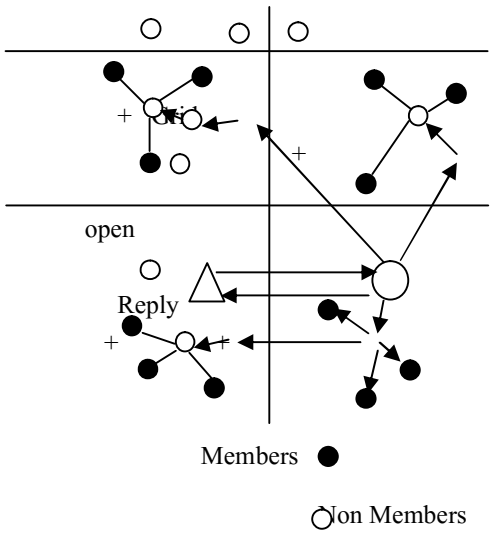

Figure 8. *Data Delivery in HGMR*

The need is to design such a protocol which provides scalability as well as forwarding efficiency.

Advantages:

- Energy efficient and encoding efficient protocol as it provides higher forwarding efficiency which utilizes multicast advantages as concept of GMR is used in HGMR.
- Scalability is improved as it has low overhead hierarchical decomposition which is the concept of HRPM.
- Less delay as compared to GMR and HRPM.

Disadvantages:

- Packets may be corrupted due to noise or the receiver may be unable to decode them due to low SNR and it increases with the packet size.
- Simple network partition may not achieve the optimal routing path from the root node to multicast group members.
- Here the routing data efficiency can be low because the data packets are always sent from the upper APs to lower APs without considering that lower APs may be closer to the source than upper APs.

8. Energy Balancing Multicast Routing Protocol for Wireless Sensor Networks (EMRP):

Energy Balancing Multicast Routing Protocol for wireless sensor networks was introduced by T. Kim et al.. The main goal of the proposed protocol is to balance the energy consumption in the network by changing the routing paths which should be maintained at the beginning of the routing process. Unless there is any topology change, there is no change in the routing paths in data delivery paths so the nodes on the routing paths can dead own to continuous energy consumption. This dynamic location based multicast protocol was proposed to balance the network energy consumption by changing the routing paths in order to improve the lifetime of wireless sensor networks. Instead of just reducing the total energy consumption in routing process,balancing of the whole network energy consumption is salutary to prolong the lifetime of the network. than just reducing the total energy consumption in routing process [22].

Advantages:

- Balance energy consumption of whole network and prolongs the lifetime of network.

Disadvantages:

- It involves more nodes and therefore consumes more energy for data delivery.

B. Features of existing multicast routing protocols

Features / protocols	stateless	real time	Data aggregation	mobility
GEAR [17]	x	x	x	✓
VLMP [22]	✓	x	x	✓
LWMP [13]	✓	x	x	✓
BAM [11]	✓	x	✓	x
ODMRP [13]	x	x	x	✓
GMR [18]	✓	x	x	x
HRPM [2][7]	✓	x	x	x
HGMR [19]	✓	x	x	x
EMRP [3][23]	x	x	✓	x

Table 3. *Features of existing multicast routing protocols*

C. Similarities and dissimilarities among the multicast routing protocols

Similarities	Dissimilarities
1.) No real time support provided by all protocols.	1.) Some protocols are stateless and some are not. 2.) Mobility and data aggregation is also uneven.

D. Comparison of different multicast routing protocols

Features / Protocols	scalability	Network lifetime	complexity	Energy efficiency	overhead	PDR	Delay
GEAR [17]	limited	Very long	Low	good	medium	high	low
VLMP [11][13]	low	Short	Low	poor	high	low	high
LWMP [13]	low	Short	medium	poor	high	low	low
BAM [11][13]	high	Long	medium	high	low	high	low
ODMRP [13]	high	Long	High	poor	high	high	high
GMR [15][18]	low	Short	High	good	high	high	high
HRPM [2][13][19]	high	Short	medium	poor	low	low	moderate
HGMR [19] [7]	Very high	Long	Low	high	low	Very high	Low
EMRP [3] [23]	high	Long	medium	good	high	high	Low

Table 4. *Comparative study of multicast routing protocols*

V. CONCLUSION

In this paper some multicast routing protocols are discussed to draw a performance comparison on the basis of some important parameters like scalability, network lifetime, algorithm complexity, energy efficiency, encoding overhead, packet delivery ratio (PDR) and latency/delay. Table 4. concludes that GEAR, BAM, ODMRP and EMRP provides long network lifetime whereas,on the other hand VLMP, LWMP shows poor performance in terms of energy efficiency. GMR protocol inculcates too much overhead but HRPM outperforms GMR by removing its drawbacks. Atlast HGMR provides better results in terms of both scalability and encoding overhead issues.

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